Rotational flywheel training in youth female team sport athletes: could inter-repetition movement variability be beneficial?

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ABSTRACT

Background: The aim of this study was to analyse the effects of an inter-repetition variable rotational flywheel training program (Variable) over standard rotational flywheel training (Standard). **Methods:** Twenty-four youth female team-sports players were randomly assigned to both training groups (Variable, *n* = 12; Standard, *n* = 12), which consisted of 1 set of 3 rotational flywheel exercises x 10-12 repetitions, biweekly for a period of 6-weeks. The participants included in Variable group were instructed to perform the movement randomly in one of the three directions (0º, 45º right, and 45º left). Measurements included reactive strength, jumping, change of direction, and sprinting tests; patellar tendon condition was also assessed. **Results:** Substantial improvements were found in vertical jump with left leg (16.9%), lateral jump with right leg (13.6%), and patellar condition in left leg (4.1%) for Standard group, but also in reactive strength index in right leg landing (33.9%), vertical jump with right (10.1%) and left leg (12.0%) for Variable group. A significant interaction effect (group x time) was observed on patellar condition in right leg ($F = 10.02$, $p < 0.01$, $\eta^2 = 0.37$), favoring Variable group. **Conclusions:** Rotational flywheel training programs were beneficial for youth-female team-sports athletes, although the movement variability may play a key role to develop different and specific physical adaptations.

Keywords. Variability; resistance training; injury prevention; between-limbs asymmetry

INTRODUCTION

Team-sports require the players ability to perform repeated bouts of high-intensity actions (HIA), such as sprinting, jumping, and cutting, interspersed with periods of low-to-moderate intensity actions [1]. While the frequency of HIA is typically higher during the first half of match-play situations, a decrease is observed towards the final moments [1]. As such, it is suggested that team-sports athletes need to maintain high levels of explosive muscular strength during the entire game, in both defense and offense phases [2]. Thus, any strength and power training program with team-sport athletes should enhance performance in HIA, in order to improve the ability to repeat them throughout a match and, consequently, avoid a detrimental effect in game performance [2].

Several training strategies have been recommended to enhance HIA maintenance during lower-body actions in team-sports athletes [3–5]. In this regard, resistance training with eccentric overload (RTEO) using a flywheel or conical pulley device, including several sets of maximal efforts is considered to be particularly effective to improve strength-related aspects [6], as well as HIA, such as jumping, sprinting, and cutting in team-sport athletes [4,7–10]. Despite the reported strength, power, and muscle mass enhancements obtained in training programs are comparable for men and women [11], RTEO has been mainly explored in male athletes [7]. In this regard, youth female athletes present some distinct physical characteristics compared to their male counterparts, which practitioners may need to consider when designing and implementing training programs [2,12–14].

Youth female athletes may be at greater risk of injuries, in particular overuse injuries (e.g. patellofemoral pain syndrome) [14], and such risk is exacerbated during puberty, due to the delay between musculoskeletal and neuromuscular systems concurrent development [12]. Consequently, risk factors such as altered timing and magnitude of muscle activation, frontal plane knee control, strength deficits, between limbs neuromuscular imbalances, inadequate muscle stiffness, and altered proprioception have already been reported [12]. Previous study involving 10-week RTEO using a conical pulley device improved unilateral lower limb strength and power in both vertical (ES = 0.12-0.82), and horizontal (ES = 0.01-0.19) directions, but also inter-limb asymmetries (horizontal ES = 0.01-0.88; vertical ES = 0.08-0.24) [9]. From this evidence, the importance of future research for considering the effect of RTEO on the development of HIA and minimize the risk of injury in female team-sports athletes can be derived.

The RTEO programs usually include exercises with force application in variable or constant vectors [4,8,9,15]. Evidence from previous studies confirm that training programs designed to promote variability between exercises (i.e. variable unilateral multi-directional training program) are more effective in lateral and horizontal directions compared to constant bilateral-vertical training [4]. These results may suggest that the neuromuscular system respond differently on movement variability. However, evidences are still scarce, particularly about the effect of inter-repetition variability during the RTEO exercises. A recent study with rugby players promoted inter-repetition variability during horizontal RTEO exercises, including the catching and throwing of a rugby ball in the concentric phase of movement [15]. This boundary condition generated higher unpredictability of body acceleration, but also a potentially distinct muscle activity, a greater adaptation of the neuromuscular system and, consequently, a reduced risk of injury [15]. Nevertheless, further evidence is required to better understand the effects of RTEO program that includes within-task movement variability. Therefore, the aims of the present study were to: analyse and compare the effects of RTEO programs in youth female basketball players, and to estimate the effect of biological maturation in training response. Furthermore, we hypothesised that Variable rotational flywheel training would be more beneficial on physical parameters and patellar condition.

MATERIAL AND METHODS

Participants

Twenty-four young (U-16) female basketball and volleyball players (age: 15.0 ± 0.5 years; height: 165.7 ± 5.4 cm; body mass: 61.7 ± 7.3 kg; MO = 2.40 ± 0.46 years) were selected from two teams to participate in this study. All participants were healthy and met the following inclusion criteria: (1) currently free of any injury within the last three months, and (2) no previous history of injury or surgery that may affect their physical performance. All participants were randomly divided into Variable (*n* = 12, volleyball = 4, basketball = 8) or Standard (*n* = 12, volleyball = 8, basketball = 4) groups. All players participated on an average of five hours of specific sport (i.e. basketball or volleyball training; 3 team-sessions/week, 90 minutes/session), and 1 competitive match (regional level) per week. None of the players had previously participated in a periodized strength training or RTEO program. Only subjects who participated in at least 90% of the workouts were considered for data analysis, which resulted in the exclusion of five players from post-testing analysis (Standard, n = 1; Variable, n= 4). Nineteen players were finally assessed. Written informed consent was obtained from all participants' parents and player ascent was obtained before the beginning of this investigation. The present study was approved by the institutional research ethics committee and conformed to the recommendations of the Declaration of Helsinki.

Training Program

An experimentally controlled trial with two consecutive measurements was designed for this study. The training program lasted 6 weeks and was carried out in addition to the regular team-sessions. The first two weeks (sessions 1 to 4) served as players' familiarization to training devices and exercises. Subjects in both groups performed two weekly training sessions prior to in-court training sessions, after a standardized warm up routine. Typical training sessions consisted of 1 set of three different unilateral exercises [4]: backward lunges (1 set of 5 repetitions each leg), defensive-like shuffling steps (1 set of 6 repetitions each leg), side-step (1 set of 5 repetitions each leg) using a portable isoinertial flywheel training device (*Eccommi, Byomedic System, Barcelona, Spain; Inertial load 315 kg·cm*^{2}) attached to an hip belt worn by the athlete (*Belt strap + Cord 360º, Iberian Sport, Spain*) (Figure 1). All the exercises started with dominant leg and were executed in the same sequential order in every session (backward lunges, defensive-like shuffling steps, and side-step). Players were encouraged to perform the concentric phase as fast as possible, while delaying the braking action to the last third of the eccentric phase. After completing the pre-established number of repetitions with one leg, the subjects change the execution leg within the set, without stopping. Three minutes of passive recovery were provided between-sets and exercises. The Standard group performed all repetitions on the same direction as previously described [4], while the Variable group, before each concentric phase, were verbally instructed by the main researcher to perform the movement in one of the three directions (1 =45º Right; 2 = 0º; 3 = 45º Left) (Figure 2), in random order. These directions were selected based on pilot studies where this setting achieved adequate movement performance, without detrimental loss of balance. No direction was repeated for more than three times.

*** *Insert Figure 1 Here****

*** *Insert Figure 2 Here****

Testing Procedures

Before the commencement of the study, a reliability analysis of the physical-fitness tests employed in the present investigation was made with all the participants in the study. Testing was completed one and two weeks before the commencement of the training period and one week after the intervention. Physical performance tests were performed under the same environmental conditions (training session time and indoor basketball court). A 10-min standardized warm-up was performed (i.e., 5 min jogging, dynamic stretching, 10 bilateral squats, core exercises, 10 unilateral squats and 3 vertical unilateral jumps). Testing sessions included the following order of tests: anthropometrical measurements, self-reported patellar tendon condition questionnaire, jumping tests (countermovement jump [CMJ], single leg countermovement jumps [SLCMJ], diagonal single-leg rebound jump [SLRJ]), T-test and straight sprinting tests (0-5 and 0-10 m splits time). Jump height was recorded using an infrared optical system (*OptoJump Next—Microgate, Bolzano, Italy*). Running and change of direction times were recorded with 90 cm height photoelectric cells separated by 1.5 m (*Witty, Microgate, Bolzano, Italy*). Each participant performed three trials of jumping, running and change of direction abilities with 2 minutes of rest between the trials. Players started each speed and change of direction tests in standing position with their foot 0.5 m behind the first timing gate.

Maturation Status. Body mass, height and seated height were recorded for estimation of somatic maturation. The MO was estimated according to non-invasive method of Mirwald and colleagues [16], however since the preliminary results did not provided meaningful inferences, it was not considered for further analysis.

Victorian Institute of Sport Assessment-Patella (VISA) questionnaire. The VISA scale is an 8-item questionnaire to assess patellar tendon condition, which has previously translated and validated into Portuguese language [17]. Questionnaire completion was conducted in a quiet group environment, lasting between around 3 minutes for either limb (VISA-R and VISA-L), under supervision of the main researcher. Each subject completed his questionnaire independently (i.e., there was no group discussion).

Jumping. Countermovement Jumps (CMJ) were assessed according to Bosco Protocol. Subjects performed three successful SLCMJs with each leg in the vertical, horizontal, and lateral directions. Subjects started standing on one leg, descend into a countermovement, and then extend the stance leg to jump as far as possible in the vertical, horizontal, and lateral directions. Landing was performed on both feet simultaneously, in vertical direction. In horizontal and lateral directions, the landing occurred on the same foot. A successful trial included hands on the hips throughout the movement and if balance was maintained for at least three seconds after landing. If the trial was considered as unsuccessful, a new trial was allowed. In horizontal and lateral directions, the subjects started with the selected leg positioned just behind a starting line.

Diagonal single leg rebound jump. Subjects stood on one leg on top of a 30-cm high box with hands placed on the hips. Then, hopped down diagonally (45º anterolateral), landed on the same leg within infrared optical system (*OptoJump Next—Microgate, Bolzano, Italy),* and then jumped vertically as high as possible with the shortest contact time as possible [18]. The reactive strength index (RSI) was automatically calculated using Optojump Next software, version 1.12.1.0 (*Microgate, Bolzano, Italy*), through the following formula: jump height /contact time [18].

T-test. T-test determined speed with directional changes (forward sprinting, lateral shuffling, and backward running) [19].

Speed tests. Average running speeds were evaluated by 5-m (0-5 m) and 10-m (0-10 m) split times.

Statistical analysis

The lower limb asymmetry index (ASI) was determined adhering to the procedures of Bishop and colleagues [20] using the following formula: *ASI = 100/Max Value (right and left) x Min Value (right and left) x – 1 + 100*. One specific Excel spreadsheets from sportsci.org were used to examine within-group (xPostOnlyCrossover.xls) comparisons. Threshold values for Cohen's d for effect sizes (ES) statistics were 0–0.2 trivial, >0.2–0.6 small, >0.6–1.2 moderate, >1.2–2.0 large, and >2.0 very large [21]. Quantitative chances (QC) of the beneficial/better or detrimental/poorer effect were assessed qualitatively as follows: <1%, almost certainly not; >1–5%, very unlikely; >5–25%, unlikely; >25–75%, >possibly; 75–95%, >likely; 95–99%, very likely; and >99%, most likely [21]. If the chance that the true value was >25% beneficial and >0.5% harmful, the clinical effect was considered as unclear. However, the clinical inference was declared as beneficial when odds ratio of benefit/harm was >66 [21]. Also, parametric related samples t-test was used to analyze within-group changes. A 2x2 repeated-measures analysis of variance (ANOVA) was performed on the absolute values of all parameters to determine the main effects between groups (SFLY, and VFLY) and time (pre, and post-test). Also, repeated measures ANCOVA with MO correcting for maturity dissimilarities was applied for all parameters to examine the training response over time. Partial eta-squared (η^2_p) was used as a measure of effect sizes, and values were interpreted as no effect ($\eta^2_p < 0.04$), minimum effect ($0.04 < \eta^2_p < 0.25$), moderate effect ($0.25 < \eta^2_p < 0.64$), and strong effect ($\eta^2_p > 0.64$) [22]. Reliability analysis was evaluated considering intraclass correlation coefficient (ICC) and coefficient of variation (CV). The level of statistical significance was set at $P \leq .05$. All statistical analyses were performed using SPSS software (version 24 for Windows; SPSS Inc., Chicago, IL, USA).

RESULTS

Each test had acceptable between-session consistency with substantial or almost perfect ICC's (Table 1).

*** *Insert Table 1 Here****

Relative changes and qualitative outcomes for both training groups are described in table 2 and 3, respectively. The Standard group showed significant improvements in CMJ$_{L}$, LJ$_{R}$, VISA$_{L}$, SLRJ$_{L}$, 0-10m, CMJ$_{R}$, HJ$_{L}$, LJ$_{L}$, CMJ$_{R}$ (Table 2). The Variable showed significant improvements in SLRJ$_{R}$, SLRJ$_{L}$, CMJ$_{R}$, CMJ$_{L}$, VISA$_{R}$, VISA$_{L}$, and T-test (Table 3).

*** *Insert Table 2 Here****

*** *Insert Table 3 Here****

The statistical analyses showed a significant main effect of time in 0-10m, T-test, CMJ$_{R,}$ CMJ$_{L,}$ HJ$_{L,}$ HJ$_{ASI,}$ LJ$_{R,}$ LJ$_{L,}$ SLRJ$_{R,}$ SLRJ$_{L,}$ VISA$_{R,}$ and VISA$_{L}$ (Table 4). There was an effect of group in LJ$_{L}$, and significant interaction effect (group x time) on VISA$_{R}$, favoring Variable group (Table 4).

*** *Insert Table 4 Here****

DISCUSSION

The aims of this study were to analyse and to compare the effects of RTEO programs, and to determine the effect of biological maturation in training response. We found that both training methods are beneficial at physical and patellar conditions levels. Thus, the present findings partially support our hypothesis that Variable rotational flywheel training could be more beneficial at physical level and patellar condition.

Jumping, sprinting and cutting use the stretch-shortening cycle (SSC), where an eccentric action (i.e. stretching) precludes a concentric action (i.e. shortening) [23]. Considering the present findings, the RTEO might induce gains at mechanical, morphological, and neuromuscular levels, which consequently increase eccentric coordination and enhance SSC performance [23]. Also, an increase of voluntary activation of agonists during eccentric contractions, motor unit firing frequency, motor unit synchronization, intermuscular coordination, and tendon stiffness (which influence the storage and return of elastic strain energy) could confer an advantage in SSC, and consequently in HIA (i.e. sprinting, jumping, and cutting) [23]. However, between-group differences in physical variables suggest that other factors underpin the distinct training responses. For example, training interventions which use movement variability (i.e. inter-repetition or intra-repetition) were more beneficial than conventional training protocols, as it generates greater neuromuscular [24,25] and neurophysiological adaptations [26], and particularly increase the storage of elastic energy during the eccentric phase, leading to larger release of kinetic energy during concentric phase [24]. This better exploitation of the SSC may have allowed a greater training stimulus to occur over time, resulting in improved sprinting, jumping, and cutting performance. Furthermore, movement variability causes brain states in which certain regions produce electroencephalographic frequencies in the alpha- and theta-bands which benefits short-term memory and learning [26]. Increased theta activity reflect multi-sensory processing required for the integration of information from different sensory modalities [26]. Thus, this multisensory movement representation might explain for better performance in HIA which include interferences from internal and external sources. However, more studies are essential to understand the medium-term effects of this kind of intervention.

Optimal movement variability during Variable rotational flywheel training could increase the need for stabilisation at lower-limbs to maintain balance posture, therefore requiring input from muscular involvement during lower limb triple flexion [24]. The enhanced muscle activity in ankle, knee, and hip joints stabilizers may underpin the between-groups differences in SLCMJs performance, in all directions. In previous studies, the SLCMJs have shown similar improvements after different training strategies [4,9]. However, the training effect in jumping and sprinting parameters appears to be of lower magnitude than those reported in studies employing RTEO [4,9,10]. These differences can be in part explained by their different training load nature [27], because of greater inertial load was used during training interventions in youth team-sports athletes *(0.11 to 0.27* $kg{\cdot}m^2$ *> 0.0315* $kg{\cdot}m^2$*)* [4,9,10]. Higher loads during RTEO exercises generate greater eccentric overload values [27], which could elicit energyabsorbing forces gains, and consequently sustain the CMJ improvement. Also, the higher overload and assist musculature of hip and knee regions involved in the SSC exploring horizontal force-vector application promote higher stimulation of neuromuscular system, contributing to a higher motor units recruitment and a better synchronization of their activation [27], resulting in a short-sprinting improvement. Furthermore, lower inertial loads *(*e.g. *0.25 kg·m²)* allows higher power levels during the concentric phase [27]. Considering the present findings (i.e. improved change of direction speed and hopping performance), this could be the suitable inertial load when aiming better performance in HIA that have dynamic correspondence with movement patterns in terms of force vector application during a training program.

Horizontal jumps, such as LJ require greater hamstring activity than the CMJ_R and $_L$ and an opposite activity of the rectus femoris [28]. Female athletes show distinct levels of hamstring and quadriceps strength throughout youth age [12], which result in different frontal-plane kinematics. For example, youth female athletes are supposed to activate a higher proportion of the lateral side of the quadriceps muscle compared with males, which may contribute to frontal-plane control changes (i.e. dynamic knee valgus) [12], and consequently variable performance in frontal and sagittal-plane–dominated tasks, such as LJ and HJ, respectively.

Both participation in jumping and landing based sports (e.g. basketball and volleyball), reduced strength of ankle- and hip-joint muscles, and impairments in both static and dynamic postural balance are key injury risk factors [29]. Despite the improvements in SLCMJs, which may be indicative of increased strength of ankle- and hip-joint muscles, and both static and dynamic postural balance [5], we cannot claim any prevention effect of the training program imposed. The previous examined chronic ankle instability (CAI) sample displayed an mean RSI value of 0.41, being lower than that displayed by those subjects without CAI (RSI = 0.50) [18]. Despite the SLRJ performance enhancement after the intervention period, both groups revealed a detrimental variation of the ability to change quickly from eccentric to concentric muscular contractions (Standard RSI = 0.28-0.29; Variable RSI = 0.34). During SLRJ, those subjects with CAI showed an altered muscle activity associated with diminished neuromuscular function, shock-absorption ability, energy storage of the Achilles tendon, contributing for lower stabilization of ankle joint in plantar-flexion, particularly during the shock-absorption phase and, consequently, for higher risk of lateral ankle sprain [18]. However, further studies are necessary to determine the suitability of the RTEO preventing soft tissue injuries in team-sports athletes. Furthermore, patella-related injuries show higher rates of activity absence in basketball, and the VISA score is an indirect measure of patellar tendon injury [8]. Even though both groups have shown likely differences in patellar tendon condition after the intervention, the Variable group presented a decreased baseline VISA score in both lower limbs, which could be indicative of an associated restricted knee function and patellar tendon injury (< 75-80 points). The enhancements in patellar tendon condition after the intervention appears to be supported by previous investigations that reported an improved VISA score after a 24-week half-squat RTEO intervention in youth basketball and volleyball female players [8]. In fact, the eccentric exercise has been widespread implemented to manage patellar tendon complaints and enhance tendon structure [8,23]. It is supported through both a tendon stiffness and cross-sectional area increases, which maximizes tendon strain necessary to optimize tendon adaptive response [23]. It appears that multidirectional RTEO might induce both qualitative and quantitative changes in tendon, although more research is necessary to clarify the real changes in patellar tendon structure. Despite the usefulness of these findings, the present study has some limitations which must be acknowledged. Firstly, the influence of biological maturation in training response should be studied according to the different maturational stages. During growth and maturation several morphological changes occur, in addition to distinct muscular unit recruitment, pre-activation, reflex control and a co-contraction decrement, which underpin variations in SSC performance [30] and, consequently, distinct training might be expected. Despite the usefulness of present findings, the present study has some limitations which must be acknowledged. First, only a small sample size was involved. Secondly, other confounding factors including the effects of menstrual cycle, oral contraceptives, and eating disorders were not controlled. Finally, it would be interesting to analyse asymmetries during change of direction tasks.

CONCLUSIONS

The rotational flywheel training is becoming popular in team-sports training programs, especially the goal includes the improvement of HIA. The present findings highlights the importance of this training devicefor youth female team-sports athletes, and especially to improve physical abilities and patellar condition. Movement fluctuations through verbal instructions could be included to enhance force absorption ability, hopping in left side of body, and manoeuvrability (i.e. multiple modes of change-of-direction movement, as defensive shuffling, backpedaling, and changes of direction). Thus, the practitioners should consider inter-repetition variability induced by verbal instruction to generate movement variability and promote distinct neuromuscular and neurophysiological adaptations.

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No potential conflict of interest was reported by the authors.

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TABLES

Table 1. Reliability data for each test

Table 2. Changes in performance after standard rotational flywheel training program

Table 3. Changes in performance after inter-repetition variable rotational flywheel training program

Table 4. Summary of Repeated Measures Analyses for the performance scores

TITLES OF FIGURES

Figure 1. Eccentric overload unilateral exercises: A) backward lunges (anteroposterior/posteroanterior), B) defensive-like shuffling steps (mediolateral/lateromedial), C) side-step (posteroanterior/anteroposterior) adapted from Gonzalo-Skok et al.[4]

Figure 2. Interrepetition variable rotational flywheel training setting and the corresponding directions. Legend: 1 =45º Right; 2 = 0º; 3 = 45º Left

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Table 1. Reliability data for each test

Variable	ICC (95%CL)	CV (%) (95%CL)	Variable	ICC (95%CL)	CV (%) (95%CL)
CMJ	0.99 (0.97; 0.99)	3.06 (2.27; 3.86)	HJ_R	0.83 (0.67; 0.92)	4.30 (2.90; 5.69)
0-5 m	0.83 (0.55; 0.93)	4.30 (2.78; 6.06)	HJ_L	0.89 (0.78; 0.95)	4.85 (3.35; 6.34)
0-10m	0.72 (0.50; 0.89)	2.96 (1.77; 4.14)	LJ_R	0.90 (0.78; .95)	5.06 (3.35; 6.76)
T-test	0.85 (0.71; 0.93)	1.90 (1.10; 2.71)	LJ_L	0.89 (0.79; .95)	5.29 (3.37; 7.22)
CMJ_R	0.89 (0.78; 0.95)	7.37 (5.29; 9.47)	$SLRJ_R$	0.81 (0.65; .92)	11.75 (7.43; 16.06)
CMJ_L	0.95 (0.89; 0.98)	6.19 (4.43; 7.95)	$SLRJ_L$	0.85 (0.70; .93)	10.20 (6.73; 13.67)

Abbreviations: ICC = Intraclass correlation coefficient; CV = Coefficient of variation; CL = Confidence limit; CMJ = Countermovement jump height; 0-5 m = 0-5 m sprint time; 0-10 m = 0-10 m sprint time; HJ = horizontal jump; LJ = lateral jump; SLRJ = Diagonal single leg rebound jump; VISA = Victorian Institute of Sport Assessment-Patella questionnaire. Legend: ↑ = Positive; ↓ = Negative; R = Right; L = Left

Table 2. Changes in performance after standard rotational flywheel training program

Variable	Pre-test, mean±SD	Postest, mean±SD	% difference (90%CL)	Standardized difference (90%CL)	Chances of better/trivial/worse effect	Qualitative assessment	p
CMJ (cm)	23.18 ± 4.37	23.89 ± 5.62	2.2 (-2.5; 7.1)	0.10 (-0.11; 0.31)	21/78/1	Trivial	.328
0-5 m (s)	1.25 ± 0.08	1.22 ± 0.07	-1.7 (-3.7; 0.4)	-0.26 (-0.58; 0.06)	63/36/1	Possibly ↑	.211
0-10m (s)	2.20 ± 0.13	2.14 ± 0.12	-2.8 (-4.5; -1.1)	-0.45 (-0.72; -0.17)	93/7/0	Likely ↑	.031
T-test (s)	12.51 ± 0.63	12.37 ± 0.52	-1.1 (-2.4; 0.3)	-0.20 (-0.45; 0.05)	50/49/1	Possibly ↑	.108
CMJ_R (cm)	11.46 ± 2.61	12.86 ± 2.23	13.6 (2.7; 25.6)	0.47 (0.10; 0.85)	89/10/0	Likely ↑	.045
CMJ_L (cm)	10.40 ± 2.05	12.12 ± 2.04	16.9 (8.9; 25.5)	0.77 (0.42; 1.12)	99/1/0	Very Likely ↑	.003
CMJ_{ASI} (%)	17.10 ± 10.64	10.77 ± 4.54	-38.6 (-65.6; 9.5)	-0.60 (-1.32; 0.11)	84/13/3	Likely ↑	.141
HJ_R (cm)	117.61 ± 20.43	121.48 ± 14.67	4.1 (-1.2; 9.6)	0.21 (-0.06; 0.47)	52/47/1	Possibly ↑	.155
HJ_L (cm)	109.26 ± 21.22	118.99 ± 15.43	10.0 (3.1; 17.3)	0.45 (0.14; 0.75)	92/8/0	Likely ↑	.036
HJ_{ASI} (%)	8.94 ± 5.87	4.81 ± 4.28	-55.8 (-77.6; -13.0)	-0.82 (-1.51; -0.14)	94/5/1	Likely ↑	.045
LJ_R (cm)	93.19 ± 14.70	105.41 ± 13.67	13.6 (7.7; 19.9)	0.71 (0.41; 1.01)	99/1/0	Very Likely ↑	.004
LJ_L (cm)	89.28 ± 21.80	95.80 ± 16.00	9.1 (-0.1; 19.2)	0.31 (-0.01; 0.63)	73/26/1	Possibly ↑	.041
LJ_{ASI} (%)	9.27 ± 7.32	10.35 ± 6.72	24.1 (-7.5; 66.6)	0.23 (-0.08; 0.55)	2/41/57	Possibly ↓	.501
$SLRJ_R$ (a.u.)	0.23 ± 0.07	0.28 ± 0.08	24.5 (4.0; 49.0)	0.58 (0.10; 1.05)	91/8/1	Likely ↑	.035
$SLRJ_L$ (a.u.)	0.25 ± 0.09	0.29 ± 0.09	16.4 (4.2; 30.1)	0.41 (0.11; 0.71)	88/11/0	Likely ↑	.020
$VISA_R$ (a.u.)	91.76 ± 13.17	92.09 ± 13.41	0.3 (-2.9; 3.7)	0.02 (-0.15; 0.19)	4/94/2	Likely Trivial	1.000
$VISA_L$ (a.u.)	91.43 ± 8.31	95.18 ± 8.41	4.1 (2.5; 5.7)	0.37 (0.23; 0.51)	97/3/0	Very Likely ↑	.003

Abbreviations: CL = Confidence limit; CMJ = Countermovement jump height; 0-5 m = 0-5 m sprint time; 0-10 m = 0-10 m sprint time; HJ = horizontal jump; LJ = lateral jump; SLRJ = Diagonal single leg rebound jump; VISA = Victorian Institute of Sport Assessment-Patella questionnaire. Legend: ↑ = Positive; ↓ = Negative. R = Right; L = Left

Table 3. Changes in performance after inter-repetition variable rotational flywheel training program

Variable	Pre-test, mean±SD	Postest, mean±SD	% difference (90%CL)	Standardized difference (90%CL)	Chances of better/trivial/worse effect	Qualitative assessment	p
CMJ (cm)	25.74 ± 2.91	25.95 ± 3.51	0.6 (-4.2; 5.7)	0.05 (-0.35; 0.45)	25/62/14	Unclear	.889
0-5 m (s)	1.24 ± 0.07	1.23 ± 0.06	-1.0 (-3.9; 2.0)	-0.17 (-0.68; 0.34)	46/43/11	Unclear	.159
0-10m (s)	2.10 ± 0.09	2.07 ± 0.06	-1.3 (-4.2; 1.7)	-0.26 (-0.85; 0.33)	58/33/9	Unclear	.182
T-test (s)	12.05 ± 0.58	11.73 ± 0.63	-2.7 (-4.9; -0.5)	-0.51 (-0.93; -0.09)	90/9/1	Likely ↑	.050
CMJ$_R$ (cm)	12.61 ± 1.92	13.84 ± 1.66	10.1 (2.9; 17.8)	0.56 (0.17; 0.94)	94/6/0	Likely ↑	.017
CMJ$_L$ (cm)	12.63 ± 2.96	13.93 ± 2.18	12.0 (2.9; 21.9)	0.41 (0.10; 0.72)	88/11/0	Likely ↑	.025
CMJ$_{ASI}$ (%)	13.03 ± 10.02	12.54 ± 6.44	26.9 (-45.0; 193.2)	0.19 (-0.47; 0.85)	15/36/49	Unclear	.903
HJ$_R$ (cm)	124.61 ± 9.07	127.80 ± 9.36	2.6 (-1.9; 7.2)	0.31 (-0.23; 0.85)	64/30/6	Unclear	.292
HJ$_L$ (cm)	122.19 ± 13.10	126.28 ± 9.87	3.6 (-3.1; 10.8)	0.29 (-0.27; 0.85)	62/31/7	Unclear	.327
HJ$_{ASI}$ (%)	4.66 ± 3.99	2.82 ± 2.13	-39.8 (-72.8; 32.9)	-0.49 (-1.24; 0.27)	75/18/7	Unclear	.286
LJ$_R$ (cm)	106.59 ± 12.28	115.35 ± 10.94	8.4 (0.7; 16.7)	0.62 (0.06; 1.18)	90/9/1	Likely ↑	.093
LJ$_L$ (cm)	106.90 ± 11.04	112.03 ± 9.75	4.9 (1.0; 9.0)	0.42 (0.09; 0.75)	87/12/0	Likely ↑	.093
LJ$_{ASI}$ (%)	5.04 ± 5.85	7.64 ± 5.65	118.9 (-2.5; 391.5)	0.57 (-0.02; 1.16)	2/11/86	Likely ↓	.204
SLRJ$_R$ (a.u.)	0.26 ± 0.06	0.34 ± 0.05	33.9 (10.2; 62.7)	1.05 (0.35; 1.75)	97/2/1	Very Likely ↑	.011
SLRJ$_L$ (a.u.)	0.31 ± 0.05	0.34 ± 0.03	12.1 (3.0; 22.0)	0.61 (0.16; 1.07)	94/6/1	Likely ↑	.041
VISA$_R$ (a.u.)	79.86 ± 17.14	91.00 ± 9.97	15.9 (4.6; 28.4)	0.56 (0.17; 0.95)	94/6/0	Likely ↑	.026
VISA$_L$ (a.u.)	78.37 ± 19.87	87.25 ± 14.76	13.4 (3.3; 24.5)	0.40 (0.10; 0.70)	88/12/0	Likely ↑	.027

Abbreviations: CL = Confidence limit; CMJ = Countermovement jump height; 0-5 m = 0-5 m sprint time; 0-10 m = 0-10 m sprint time; HJ = horizontal jump; LJ = lateral jump; SLRJ = Diagonal single leg rebound jump; VISA = Victorian Institute of Sport Assessment-Patella questionnaire; Legend: ↑ = Positive; ↓ = Negative. R = Right; L = Left

1

Table 4. Summary of Repeated Measures Analyses for the performance scores

Variable	Repeated Measures ANOVA								
	F_{TIME}	η^2_p	p	F_{GROUP}	η^2_p	p	$F_{TIME\ X\ GROUP}$	η^2_p	p
CMJ (cm)	0.83	0.05	0.377	1.37	0.08	0.258	0.24	0.01	0.631
0-5 m (s)	1.93	0.10	0.731	0.01	0.00	0.923	0.12	0.01	0.731
0-10m (s)	6.85	0.26	0.027	3.19	0.16	0.092	0.81	0.05	0.380
T-test (s)	8.26	0.33	0.011	4.35	0.20	0.052	1.29	0.07	0.271
CMJ$_R$ (cm)	10.87	0.39	0.004	1.29	0.07	0.272	0.05	0.01	0.829
CMJ$_L$ (cm)	21.58	0.56	0.000	3.96	0.19	0.063	0.41	0.02	0.528
CMJ$_{ASI}$ (%)	1.44	0.08	0.247	0.20	0.01	0.663	1.06	0.06	0.318
HJ$_R$ (cm)	2.29	0.12	0.149	1.05	0.06	0.320	0.02	0.02	0.885
HJ$_L$ (cm)	5.80	0.25	0.028	2.15	0.11	0.161	0.97	0.05	0.339
HJ$_{ASI}$ (%)	5.60	0.25	0.030	3.68	0.18	0.072	0.82	0.05	0.378
LJ$_R$ (cm)	20.37	0.55	0.000	4.23	0.20	0.055	0.55	0.03	0.468
LJ$_L$ (cm)	4.90	0.22	0.041	5.83	0.26	0.027	0.07	0.01	0.796
LJ$_{ASI}$ (%)	2.34	0.12	0.145	1.55	0.08	0.230	0.40	0.02	0.536
SLRJ$_R$ (a.u.)	17.19	0.50	0.001	2.72	0.14	0.117	0.83	0.05	0.833

$SLRJ_L$ (a.u.)	11.52	0.40	0.003	3.43	0.17	0.082	0.06	0.01	0.806
$VISA_R$ (a.u.)	10.35	0.38	0.005	1.21	0.07	0.287	10.02	0.37	0.006
$VISA_L$ (a.u.)	24.52	0.59	0.000	3.21	0.16	0.091	4.01	0.19	0.062

Abbreviations: CMJ = Countermovement jump height; 0-5 m = 0-5 m sprint time; 0-10 m = 0-10 m sprint time; HJ = horizontal jump; LJ = lateral jump; SLRJ = Diagonal single leg rebound jump; VISA = Victorian Institute of Sport Assessment-Patella questionnaire. Legend: R = Right; L = Left. The partial eta squared values (η^2_p) should be interpreted as no effect (η^2_p < 0.04), minimum effect (0.04 < η^2_p < 0.25), moderate effect (0.25 < η^2_p < 0.64), and strong effect (η^2_p > 0.64).